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September 1927 Botanical Series Vol. XIV, No. 8

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Studies on the Bajri Crop.

I. The Morphology of Pennisetum Typhoideum

BY

S. V. GODBOLE, M.Sc., B.Ag.

AGRICULTURAL RESEARCH INSTITUTE, PUSA

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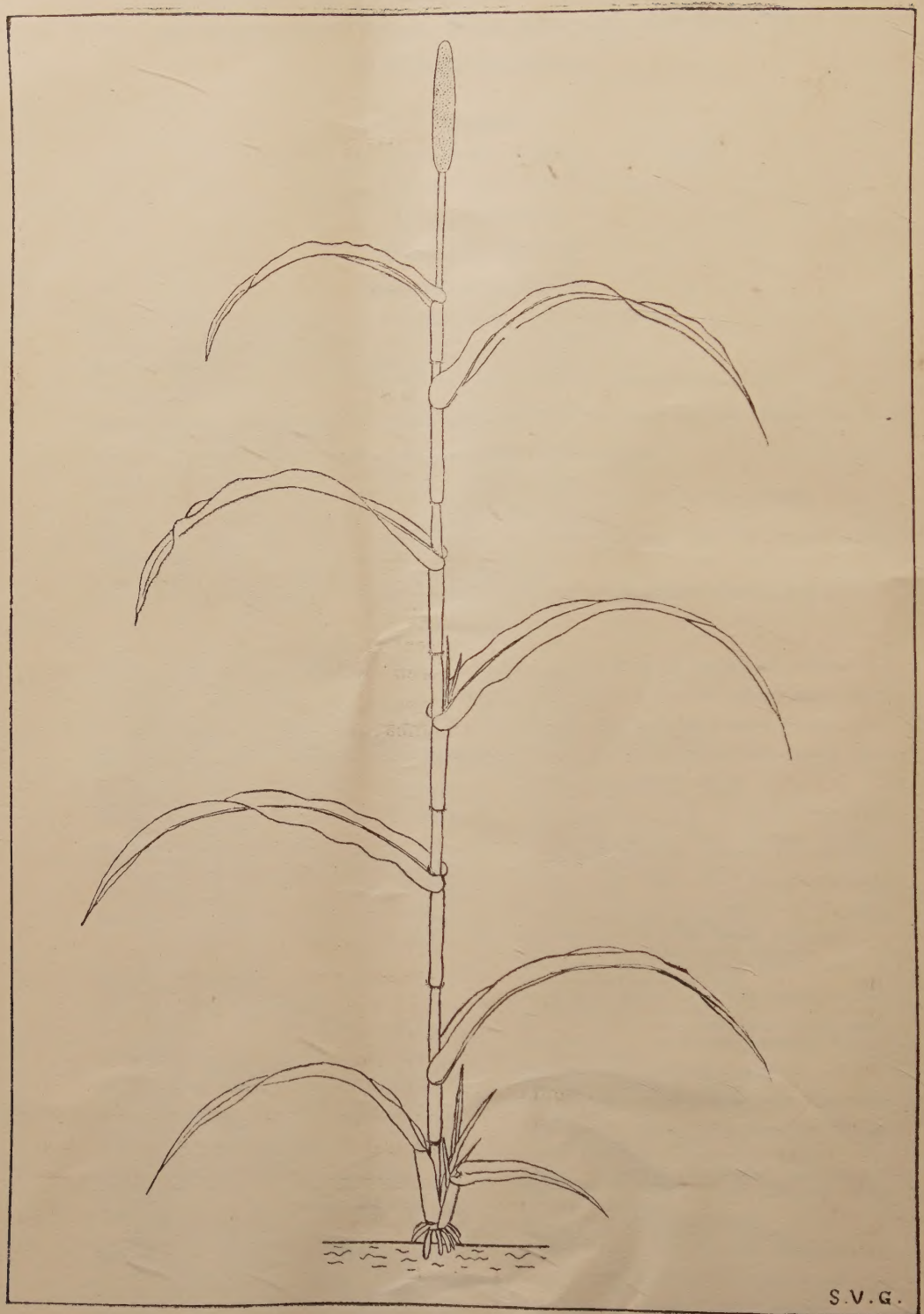
PLATE I.



The *Bajri* plant.

PENNISETUM TYPHOIDEUM.

STUDIES ON THE *BAJRI* CROP.

I. The Morphology of *Pennisetum typhoideum*.

BY

S. V. GODBOLE, M.Sc., B.Ag.

(*Received for publication on 21st December 1926.*)

Introduction.

Among the grain crops of India the fourth place is occupied by *bajri* (*Pennisetum typhoideum*), otherwise known as cat-tail millet, bulrush millet, or pearl millet. In the Bombay Presidency where the present studies have been made, it is still relatively more important, and annually occupies between four and five million acres, standing only second to *jowar* (*Andropogon Sorghum*) in the area occupied. The actual area in the several divisions of Bombay in 1924-25, the last year for which we have records, was as follows :—

	Acres
Gujarat	368,120
Deccan	2,404,659
Karnatak	303,510
Konkan	*Nil.*
Sind	1,028,729

The total amounts to 13 per cent. of the net cropped area of the Western Presidency, spread all over the province with the exception of the heavy rainfall tracts near the West coast, where it entirely disappears.

*Bajri** is the staple crop of a large tract and is the food of large classes of the people, but is grown only where it gives better results than *jowar*. It is a light soil millet while *jowar* is chiefly found on heavier soils, though on much of the land the crops are alternative, according as the weather conditions are more favourable for one or the other. It is entirely a rains crop and the area fluctuates considerably

* The general note on the crops which follows is largely taken from P. C. Patil, The Crops of the Bombay Presidency ; their Geography and Statistics. *Bombay Dept. of Agriculture*, Bulletin No. 109 (1922).

from year to year. When the monsoon opens with liberal rainfall, *jowar* occupies a larger area, while when the early rains are deficient the land put under *bajri* tends to increase. In the Deccan, the tract where *bajri* growing is most intense lies in the Western part of the so called " Desh." The crop does well on somewhat less rainfall than is required by *jowar* grown as a rains crop. In Sind, it is the dominant cereal crop of Lower Sind, next to rice, and is very largely grown here, because *jowar* is so damaged by borer (*Chilo simplex*) as to be almost a failure as a crop.

It is in very many areas grown as a mixed crop, chiefly with *Cajanus indicus* or pigeon pea. If heavy rain falls when the crop is in flower, it suffers much, and hence in the Bombay Presidency proper, it is generally sown later than other rains cereals to avoid heavy showers during this stage of its growth.

As it is generally sown on poorer land, the average yield is low, being about 400 pounds of grain and 1,000 pounds of straw per acre for the Bombay Presidency proper. In Sind the yield is very much higher.

Bajri, as a nutritious food, stands very high and compares very favourably with *jowar*. The straw, however, makes poor fodder, much poorer than *jowar* straw.

The main interest which *bajri* has, however, as an agricultural crop, is that it is highly resistent to drought, and can be grown on light and fairly shallow lands in the very precarious rainfall tracts in the Deccan and similar regions. The crop on this type of land is not a big one, but it is bigger than would be given by any other cereal, and the study, of which the present paper is the first fruit, was definitely undertaken in order to isolate strains specially highly resistent to drought. This has led to a careful morphological study of the plant itself as it occurs in Western India, and the present account is based on the material thus collected.

Name, History and Geographical Distribution.

The genus *Pennisetum* of the *Gramineæ*, according to Hooker, consists of thirty to forty species confined to the warmer regions of the world. About seven of these species are found in Western India, but *Pennisetum typhoideum* is the only cultivated species.

Very little is known about its history and the place of its origin. Nothing is known about its wild form. Kornicke[1] refers to the few opinions held by different authors, indicating either India or Africa as the place of origin. Sawer[2] states that it is a native of tropical Asia, Nubia and Egypt. Hooker suggests that its abundance throughout Africa would point to that continent as its source, while Ball[3] is of opinion that tropical Africa is its home.

The evidence on which some of these opinions are given depends on the wide and specialised use made of the crop in the various regions mentioned. Sawer, for

[1] F. Kornicke & E. Werner. *Handbuch der Getreudebaues*, Vol. I, P. 284 (Berlin 1885).
[2] E. R. Sawer. Bulrush or Munga millet. *Cedara Memoirs on S. Africa Agric.*, Vol. I, p. 293 (1909).
[3] C. R. Ball. Pearl millet. *U. S. A. Dept. of Agriculture Farmers' Bull.* No. 168.

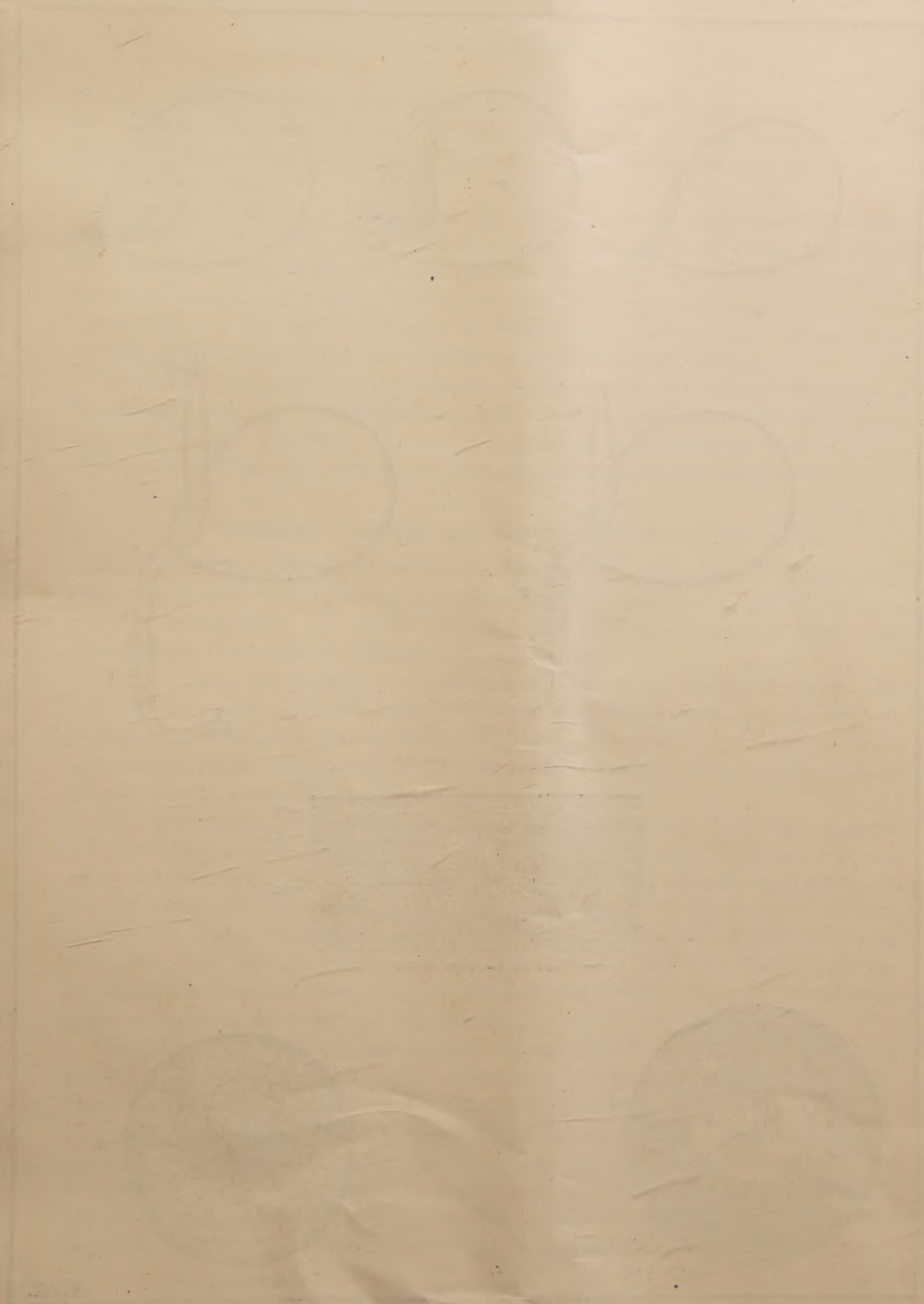
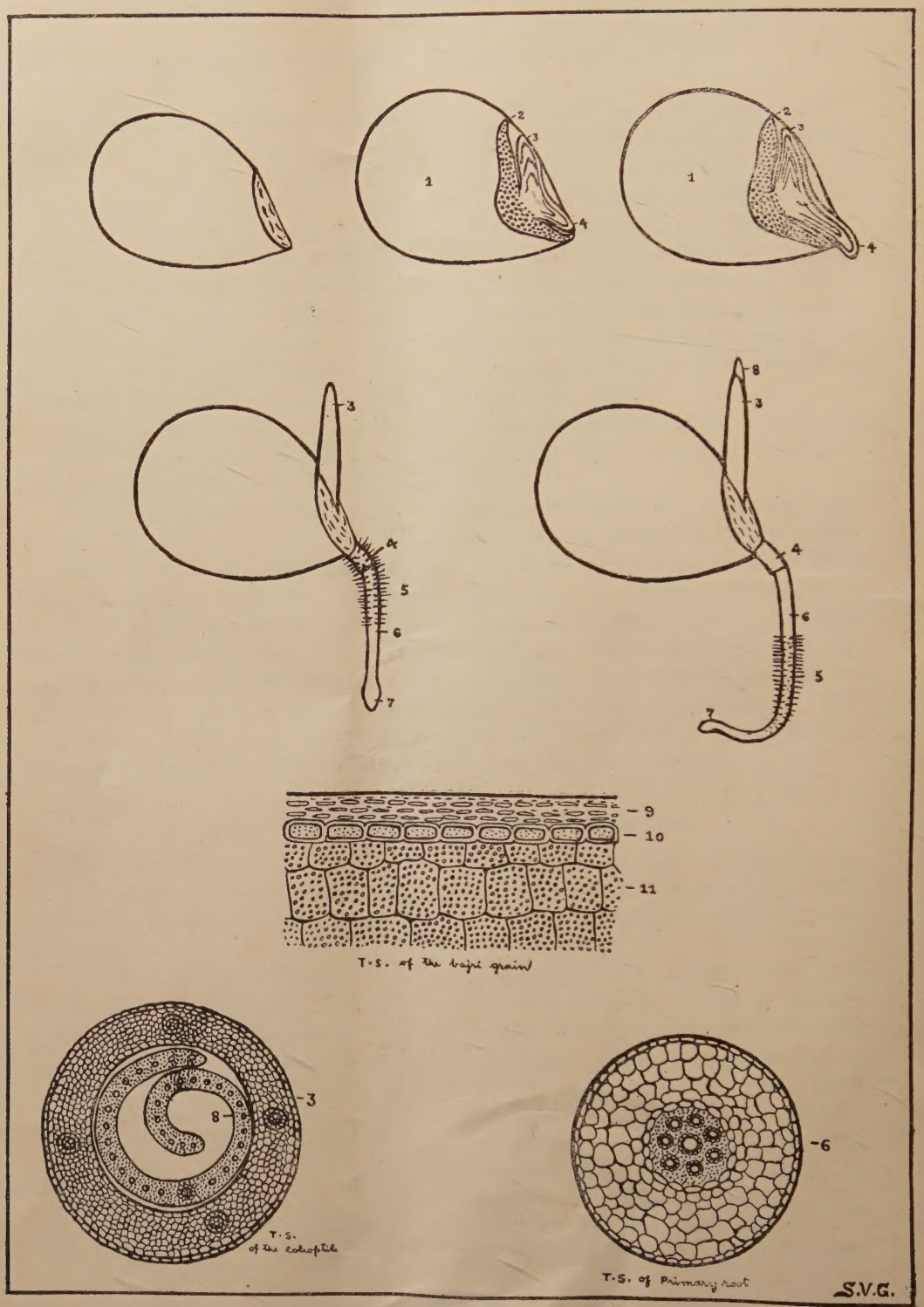


PLATE II.



The seed of *Bajri* and the young seedling.

1, Endosperm. 2. Cotyledon. 3. Coleoptile. 4. Coleorhiza. 5. Root hairs. 6. Primary root. 7. Root cap. 8. First leaf. 9, Pericarp. 10. Aleurone layer. 11. Starch parenchyma.

instance, notes that among many African tribes and particularly among the Mashonas it is used as a famine crop being planted when maize or other millets (such as *Eleusine coracana*) fail. It is valued by them as being cultivable with profit on soil too poor for maize.

Whatever be its origin, its present cultivation is very widespread. Apart from South and Central Africa, Ball notes that it has been grown in Arabia and Egypt for more than three hundred years, and that it is also extensively cultivated in Southern Europe. It was probably carried to America at a very early date, and was introduced into the United States in the fifties of the last century. There it has steadily gained appreciation of its value for grain and green fodder.

In India it is grown in all Provinces except Burma and Assam. Bombay has the greatest area, four to five million acres. Next in importance are the Punjab and the United Provinces, in each of which there are between two and three million acres. The total area in India is about sixteen million acres annually.

Structure, Viability, and Germination of the Seed.

In size and shape, the seed of cultivated *bajri* is extremely variable, being usually from 3 to 10 mgm. in weight and in appearance almost oval, with one of its ends more or less tapering. It is by this end that it is attached to the spike. Its colour varies from whitish yellow to dull light blue.

The pericarp has usually a smooth and shining surface, though there are cases when all the grains in a head have the surface very rough at the broader end. It consists of a series of elongated, thick-walled cells, five or six in number, arranged one over the other. The colour of the grain is the colour of pericarp ; the contents do not vary appreciably in tint. (Plate II).

The endosperm, as in other cereal grains, fills the whole of the interior of the grain except the small space occupied by the embryo. It may be divided into two parts, the aleurone layer and the starch parenchyma. The aleurone layer surrounds the rest of the endosperm and is one cell thick, the cells being twice as long as they are broad. The starch parenchyma consists of thin walled polyhedral cells with their long axes arranged usually at right angles to the surrounding pericarp. Adjoining the aleurone layer, they are comparatively small, becoming two or three times as large in the centre of the endosperm.

The embryo consists of a short central axis terminated above by the plumule and below by the radicle, and bearing from its middle portion the large cotyledon. The plumule remains completely enclosed in the firm cylindrical coleoptile.

Viability. Very few data could be obtained as to the length of time during which the seed remains viable under the conditions of the Bombay Deccan. We were able to make tests in 1925 of samples from the crop of every year since 1919. These had been stored with naphthalene balls to keep off insects. The seed of 1919 had been kept in a bottle ; all the rest had been preserved in paper packets.

The results of germination tests with this stored seed in 1925 were as follows :—

	Per cent. germination.
1919	51
1920	37
1921	73
1922	88
1923	93
1924	97

The higher figure for 1919 over 1920 may be the result of keeping the former in a bottle.

Germination of bajri seed. When *bajri* seed is placed under suitable conditions for germination, it first absorbs 50 per cent. of water and swells. In twenty-four hours the coleorhiza appears from the pericarp and twelve hours later the primary root breaks out. Almost at the same time, the plumule breaks through the pericarp. The coleoptile remains intact, however, until it reaches the surface of the soil. (Plate II.)

The depth to which *bajri* seed may be planted with success has an important bearing on the question of the improvement of the crop. Planting at different depths was tried in the case of the Deccan variety in the cold as well as the rainy season. The cold weather results show that in all cases where the seeds were planted more than ten centimetres deep, no leaves were able to reach the surface, and that the maximum elongation of the epicotyl was only six centimetres.

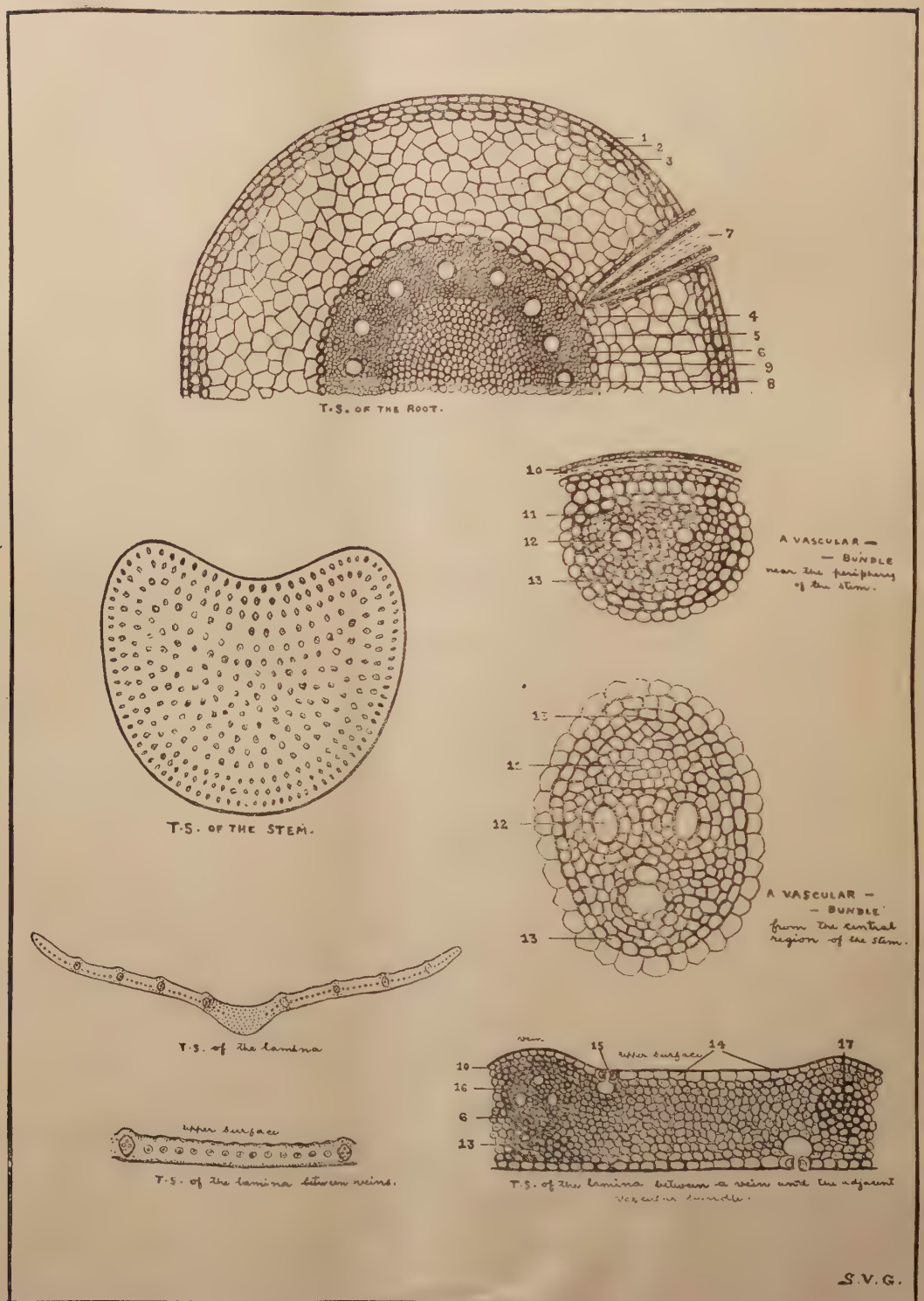
In the wet season seedlings from such depths as thirteen centimetres have come above the ground and the maximum elongation of the epicotyl in their case was ten centimetres.

The Root System of Bajri.

The embryonic plant gives rise to only one primary root, which on bursting through the coleorhiza continues downwards giving rise to lateral branches throughout its length. The lateral branches are extremely delicate, being not more than one-fifth of a millimetre in diameter. The work of the primary root is soon supplemented by secondary roots, springing from the first and still higher nodes of the plant. These do not begin to appear until two or three leaves have appeared above the surface. The first to rise is a pair of roots from the first node of the plant, each of them being one right angle away from the first axillary bud. These do not, however, appear simultaneously on both sides.

On the second node, another pair develops in like manner, and from each succeeding node two further roots appear, arranged similarly with regard to the nodal bud. At the base of the stem, near the ground, where the internodes are longer, four or six roots are produced at each node. The upper series of these usually form very strong props, which assist in keeping the plant erect. Each tiller develops its

PLATE III.



The structure of the root, stem and leaf of the *Bajri* plant.

1. Piliferous layer. 2. Exodermis. 3. Cortex. 4. Endodermis. 5. Pericycle. 6. Phloem group. 7. Root branch. 8. Xylem group. 9. Pith. 10. Epidermis. 11. Phloem. 12. Trachea. 13. Sclerenchyma. 14. Hygroscopic cells. 15. Stoma. 16. Xylem. 17. Vascular bundle.

own independent system of secondary roots, which follow the same general arrangement in pairs as that of the primary stem.

Types of root system. The root system of a good many plants has been examined by * Weaver's method, which though laborious seems satisfactory. The following notes were made as a result of the examinations made by this method.

(1) In tillered plants, the root system spreads very widely in all directions, the extent being largely determined by the number of tillers.

(2) The horizontally spreading roots are confined to the uppermost ten or twelve centimetres of soil. They are, however, much thinner than those which go downward.

(3) Each secondary root starting from the base of the plant, gives off very thin lateral branches at angles varying from seventy to ninety degrees.

(4) Types of *bajri* with a spreading habit have a much greater amount of horizontal roots, and these are mostly confined to the surface layers of the soil.

(5) When the vertical roots penetrate crevices in *murum* (the soft rock resulting from the degradation of Deccan trap) they become very much thickened, apparently as a means of widening the crevices.

(6) The excavated plants which were allowed to remain connected with the soil by a very few roots, continued to live normally for the rest of their life,—over four weeks,—and flowered and fruited quite normally. This gives an idea as to how the plant can flourish on a very much diminished root system.

(7) When sub-irrigation was used in pots, the roots altered their character and were largely attracted to the moist layer, and even to the lowermost layer of gravel in pots 26 inches deep.

Anatomy of the roots. A transverse section through a well developed root shows the following tissues (Plate III) :—

(1) The outer piliferous layer of thin-walled elongated cells, from many of which root-hairs are developed.

(2) The exodermis consisting of two or three layers of thick-walled cells beneath the piliferous layer.

(3) The broad cortex made up of five or six layers of thin parenchymatous cells.

(4) The endodermis, which is a single layer of cells with thick inner walls.

(5) The pericycle, consisting of one layer of cells, with cell walls thickened on all sides.

(6) The xylem and the phloem groups arranged alternately in a ring, and lined from within by a band of sclerenchymatous fibres.

*J. E. Weaver. Ecological Relations of Roots. *Carnegie Institute, Wash. Pub.* 286. (1919).

(7) The central portion of the stele consisting of moderately thick-walled parenchymatous cells.

The Stem of the Bajri Plant.

The stem which originates from the embryonic shoot grows on continuously into the shoot proper and consists of several segments or internodes joined together by structures known as nodes. The whole length of the lower and much of the upper internodes is invested by leaf sheaths. From each node there is produced one leaf and one axillary bud. The latter may either remain dormant or grow into a tiller or axillary shoot according to its position under or above ground. At the uppermost node, however, the bud is absent and from that node the inflorescence appears.

The Internode. The lengths of several internodes increase from the base to the apex of the stem except the lowermost four or five which are very condensed. About the time of flowering, the topmost internodes, however, show an extraordinary rate of increase in their length. Each individual internode is thickest in the middle and tapers more or less evenly towards both ends. It does not possess any cavity within. Its thickness also varies considerably, 4-7 mm. being the usual range of diameter at the middle. In some varieties, hairs are also found on the upper part of the internodes which are not covered over by leaf sheaths. Frequently, internodes of a reddish colour are also met with, especially at the base of plant.

The node. The nodes of an individual plant are all hairy, the quantity of hairs at each node increasing from the base to the apex of the stem. The extent of hairiness also varies in different strains, some being more hairy and others less so. Very frequently, plants with reddish or reddish brown nodes are met with.

The length and thickness attained by an individual plant is influenced by a number of independent factors and varies very much according to the variety and other conditions. In crops of the local variety grown by the author at Poona, the height has in extreme cases reached 203 centimetres (81 inches), but most frequently was between 100 and 150 centimetres, (40 to 60 inches). (Plate VI. Fig. 1-A.)

Anatomy of the stem. A transverse section through the stem presents the following structures. (Plate III.)

(1) The epidermis consisting of a single layer of cells with walls very much thickened from outside.

(2) The cortex consisting of one or two layers having more or less thickened cell walls.

(3) The ground tissue made up of thin-walled parenchyma extending from the cortex to the centre of the stem.

(4) The vascular bundles : in the peripheral region of the stem there are usually broader and more closely distributed than those in the central part. They contain air spaces on the inner side of the xylem portion and are surrounded by sheaths of sclerenchyma.

Tillering in the Bajri Plant.

Although tillering is of very frequent occurrence in the *bajri* plant, and though it may arise from any of the underground axillary buds either of the main stem or of its branches, yet it is only found to a small extent among the plants of a field crop of *bajri*. As studied in the case of the Deccan variety at Poona in 1921, the following shows the extent of its occurrence among plants in rows in the middle of an ordinary field of this crop :—

	per cent.
Plants without tillers	75·4
Plants with one tiller	10·6
Plants with two tillers	9·3
Plants with three tillers	4·0
Plants with four tillers	0·7

The absence of tillers does not, therefore, arise from any lack of capacity to produce tillers, and these latter develop profusely when plants either occur near a water channel, or are widely spaced, or are highly manured. When the main shoot is arrested in growth owing to disease or damage, tillers develop profusely and if the main shoot lies flat owing to trampling or to heavy rain, tillers will spring up in large numbers. Plants growing in the cold weather and consequently stunted, often give many tillers; and late varieties have often a larger number of tillers than others.

Axillary Branches or Shoots in Bajri.

The presence of frequent axillary branches, arising from the axils of the main stem, is rather characteristic of the *bajri* plant. They are not, however, anything like so vigorous as the tillers referred to above, and only develop usually two or three internodes. They are found with very great frequency in lodged plants and in those from which the upper portions of the main stem are cut off.

The relationship between the number of tillers and such axillary branches was determined in the central portion of a *bajri* field of the Deccan variety in 1921. 301 successive plants were examined with the following results :—

Number of tillers.

No. of axillary shoots	No tiller		One tiller		Two tillers		Three tillers		Four tillers	
	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.
0	179	78·8	20	62·5	17	10·7	3	25·0	2	100·0
1	34	15·0	7	21·9	5	17·9	4	33·3	0	0·0
2	9	4·0	4	12·5	5	17·9	3	25·0	0	0·0
3	3	1·3	0	0·0	1	3·5	1	8·3	0	0·0
4	2	0·9	1	3·1	0	0·0	1	8·3	0	0·0

It will thus be seen that there seems to be a greater portion of axillary shoots among tillered plants than among those without tillers. This may mean that the environment which favours tillering also favours branching, or it may mean that plants which tend to produce tillers also tend to produce the other type of branches.

The Foliage Leaves.

The foliage leaves of *bajri* are arranged on the culms alternately, in two opposite vertical rows, each leaf having a divergence of 180° from the next above and below it.

The sheath, which is somewhat thicker than the lamina, encircles the culm completely. The inner portion of the sheath is rather white and somewhat transparent. The outer surface of the sheath is usually glabrous ; but there are some plants often found in this crop in which the outer surfaces of the sheaths are clothed with short hairs. This hairiness is, as a rule, associated with that of the lamina. Occasionally sheaths, especially basal ones, with a reddish outer surface are also met with.

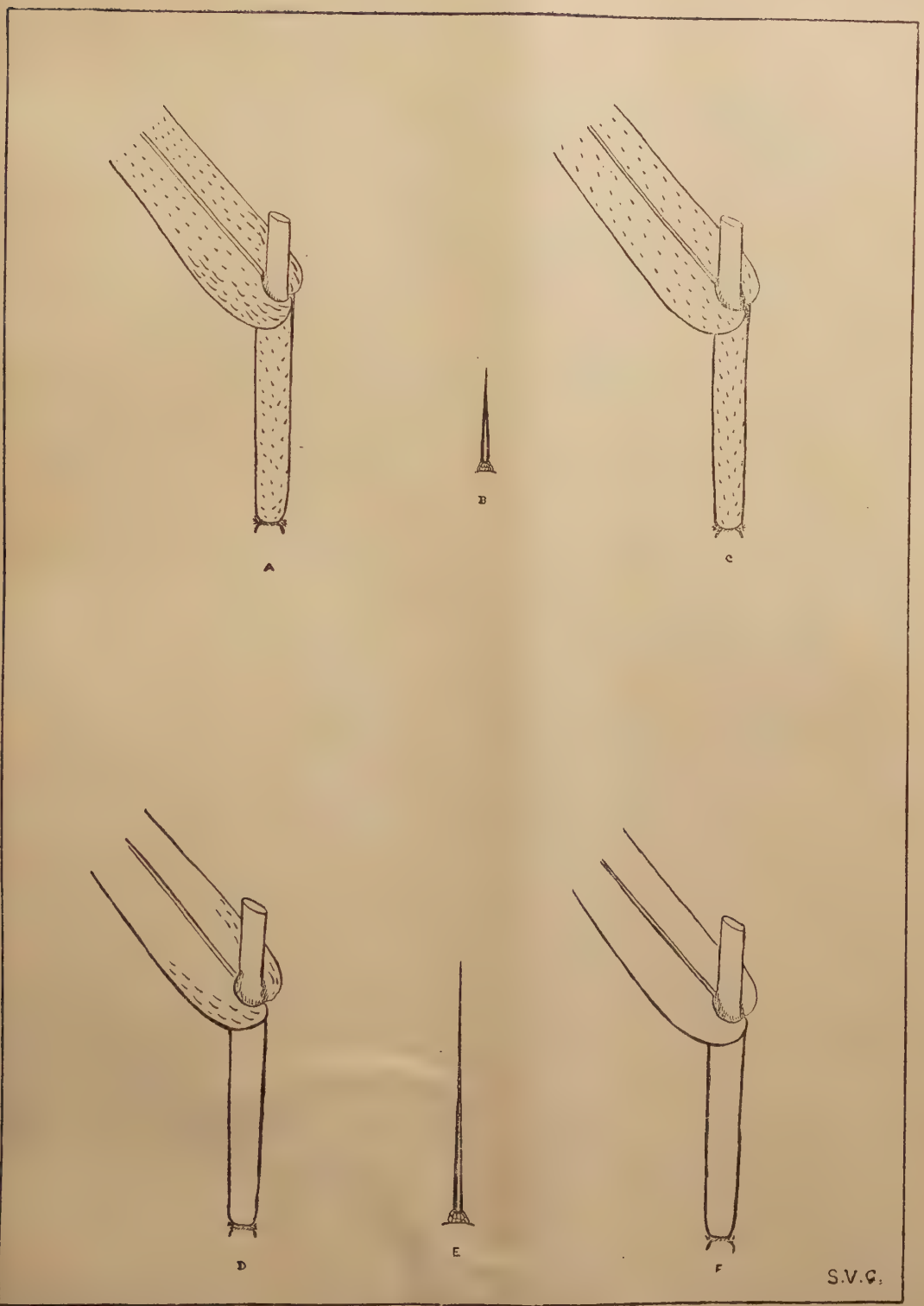
The lamina or the leaf blade is linear and parallel veined. The upper surface of the blade possesses a series of longitudinal and slightly raised ribs which are absent on the lower and hence the lower surface is usually smoother than the upper one. In the majority of plants the basal portion of the lamina possesses hairs along the upper margins, while plants without hairs also exist. These hairs, being three to four times longer than the sheath and lamina hairs, can be easily distinguished from the latter. When the lamina is hairy, hairs similar to the sheath ones are to be found on both the surfaces throughout. (Plate IV.)

The ligule closely surrounds the stem just above the leaf sheath, and is a small white structure four to five mm. in length with hairs starting from its edge.

The length of different leaf blades varies according to their position on the main stem. When the aerial part of the stem possesses four or five leaves only, the third leaf from the top is usually the longest and that next above it will probably be the broadest ; but in cases of stems having six or seven leaves, the fourth leaf from the top will have the maximum length and the one immediately above it will have the greatest width. Thus, the position of the leaf having the maximum length or breadth on the main stem will descend with the increase in the total number of leaves.

Stomata are found on both surfaces of the leaf approximately to the same extent. The number of stomata per square millimetre on the lower surface varies usually from fifty to eighty, the vigorously growing plants possessing a smaller number.

Anatomy of the leaf. The epidermis of the leaf blade consists of rectangular cells arranged in parallel rows along the long axis. (Plate III). Parallel to the midrib of the leaf blade and spaced at regular intervals there is a series of veins each having a single vascular bundle. These vary in size, every tenth to fifteenth one being much larger than the others. The larger veins are found to be slightly raised on the upper surface while they are flush with the lower.



The characters of the sheath and lamina hairs of the *Bajri* plant.

A. Long hairs at the base of the lamina and short hairs all over the sheath and lamina. B. A short hair. C. Short hairs all over the sheath and lamina. D. Long hairs at the base of the lamina. E. A long hair. F. Absence of hairs.

The epidermal cells over the veins are usually elongated and thick-walled. Unicellular hairs which are present on both the surfaces of the lamina are found on the side of these veins especially the larger ones. At the bases of the veins on both sides there is usually a single line of stomata.

Between two veins of the upper epidermis there occur longitudinal groups of motor or hygroscopic cells which contain water under normal conditions. When transpiration is excessive these cells lose their water content and cause the upper surface to shrink and curve inwards, tending to check any further loss through the stomata.

Vascular bundles found usually below the large veins are similar to those of the stem. They possess sheaths of sclerenchyma often extending up to the epidermis. The xylem and the phlœm of these bundles are situated towards the upper and the lower surfaces respectively. The smaller bundles possess sheaths of cells containing a large amount of chlorophyll.

The Bajri Inflorescence.

The inflorescence of *bajri* is a terminal compound spike with a variable number of rachillæ spirally arranged round the central axis. The rachillæ, which vary considerably in their length, bear at their apex a whorl of bristles enclosing usually two spikelets, each of which consists of a male and a hermaphrodite flower. The rachillæ, spikelets, flowers, etc., will be discussed under separate headings.

The node at which the inflorescence is borne on the main stem. Within five or six weeks from sowing, the *bajri* plant puts forth its inflorescence. This is, however, marked by the rapid increase in the height of the plant owing to the lengthening of the peduncle and the internodes below it. Earliness or lateness is roughly determined by the number of internodes that the plant possesses, since the period of growth will also increase along with the number of internodes. It was thought necessary to possess some data as to the variation in the number of internodes that the main stem has under crop conditions. This could not be done completely owing to the great difficulty of counting the internodes below the ground level and hence the counting had to be confined to the aerial portions only.

For this purpose the node at which the inflorescence appeared, counting from the ground level, was recorded in 1921 in the case of 297 plants of the Deccan variety of this crop occupying the centre of a normally grown field. The following results were obtained.

	Per cent.
Plants with three nodes below inflorescence	1·0
Plants with four nodes below inflorescence	25·3
Plants with five nodes below inflorescence	38·0
Plants with six nodes below inflorescence	31·0
Plants with seven nodes below inflorescence	4·4
Plants with eight nodes below inflorescence	0·3

Five internodes was the most frequent number possessed by 38 per cent. of the crop plants. Three and eight internodes were the extreme cases. (Plate VI, Fig. 1. B).

The rachis. The rachis or the axis of the inflorescence is a straight solid cylindrical structure, as long as the length of the earhead. It tapers more or less gradually towards its apex. It possesses a thick coating of soft short hairs all over. It is usually unbranched and in rare cases it may divide itself into two or three branches. An extremely rare instance was noticed in which it possessed in all seven branches.

The thickness of the rachis varies considerably. In some varieties, for instance in the *Gajwel* variety, the circumference often measures as much as twenty-five millimetres, while in the Deccan variety it is much less. The measurements of fifty rachides chosen at random from a normally grown crop of the Deccan variety are given in the following Table :—

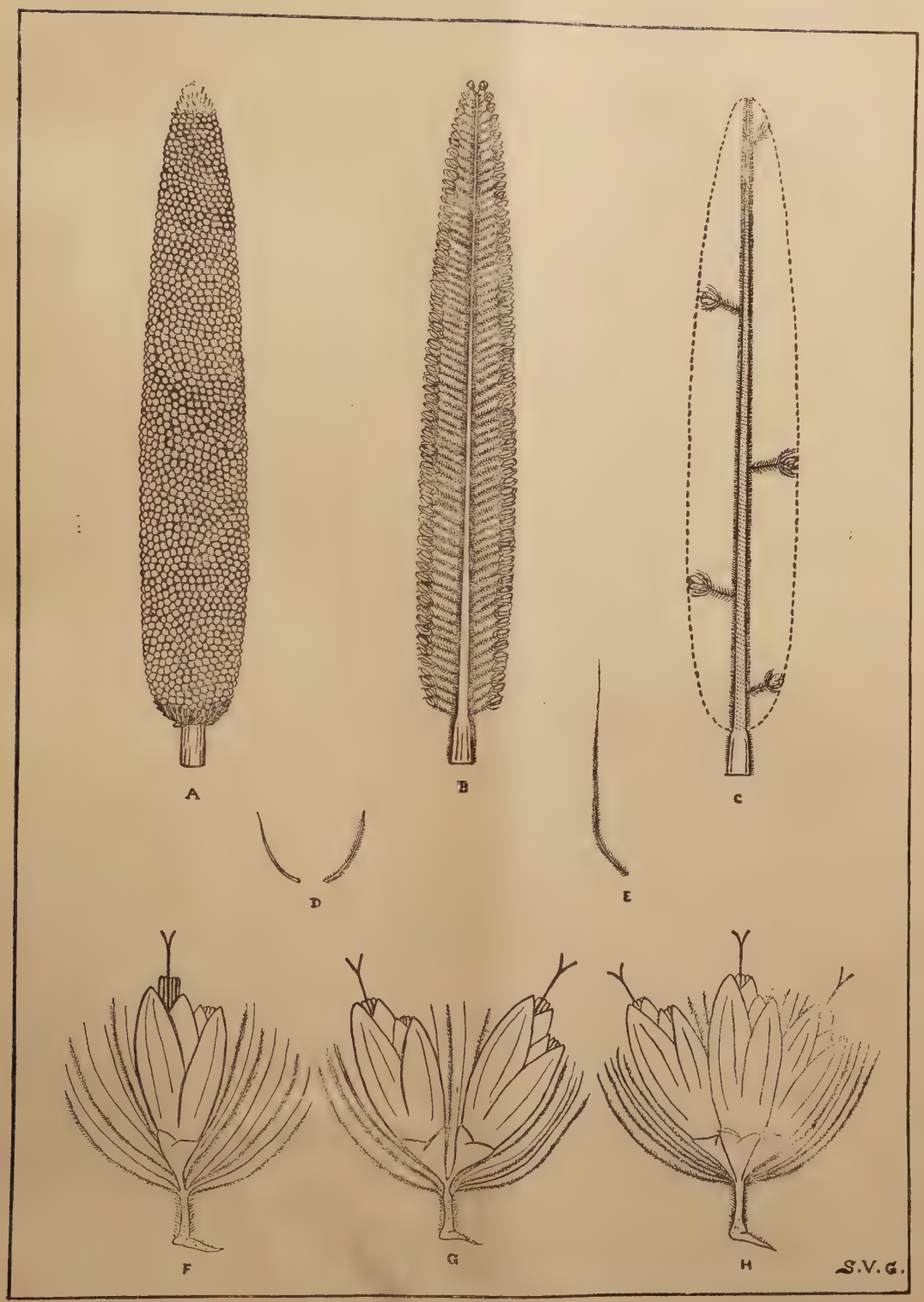
Circumference of the rachis at the middle	mm. 5	mm. 6	mm. 7	mm. 8	mm. 9	mm. 10	mm. 11
Number of ear heads in each	1	1	11	15	15	6	1
Percentage	2	2	22	30	30	12	2

Eight or nine millimetres was the most frequent circumference of the rachis with five and eleven millimetres as extreme cases. The plants did not include any types with thick rachis. (Plate VI, Fig. 2-A.)

There seems to be a negative correlation between the thickness of the rachis and the length of the rachilla. The rachillæ have very short length in the case of heads having very thick rachis, but the reverse is true only to a limited extent, for thin raches are not necessarily associated with long rachillæ.

The rachillæ. The rachillæ or the secondary axes of the inflorescence are a series of small structures arranged spirally round the central axis, each carrying a group of spikelets enclosed in a whorl of bristles at their apex. They are inclined to the rachis at varying angles, the ones in the middle being usually of 80°, while those towards the base and the apex gradually decrease until they become as small as 30°. The surface of the rachillæ has a thin covering of elongated hairs unlike that of the main axis. (Plate V A—E.).

In thickness the rachillæ are scarcely a millimetre, but their length varies considerably from 1 to 7 millimetres in different types and also in different regions of the same spike. In types with a very thick rachis, the rachillæ are extremely short, so also in some other varieties of this crop, for instance the African bulrush millet. The rachillæ in the second or the third fifths of a spike are usually the longest, while those below and above it gradually shorten until their length reaches its minimum in the uppermost part of the spike.



The earhead of the *Bajri* plant.

A. An earhead. B. An earhead showing the arrangement of rachillæ. C. A rachis with a few rachillæ. D. Ordinary bristles with and without hairs. E. An elongated bristle with hairs. F. A rachilla with one spikelet. G. A rachilla with two spikelets. H. A rachilla with three spikelets.

The length of the rachillæ and their inclination to the rachis are together partly responsible for the thickness of a particular region of the spike. In cases with very short rachillæ, the deficiency is usually made up by the greater thickness of the central axis. The varying length of spikelets also contributes to some extent to the thickness of the spike.

The number of rachillæ per earhead. In order to study the variation in the number of rachillæ per earhead, fifty main earheads were selected at random from a normally grown crop of the Deccan variety of *bajri*. The results are given in the following Table :—

No. of rachillæ per ear head	500	600	700	800	900	1000	1100	1200	1300	1400
No. of earheads .	2	4	6	10	7	7	6	2	5	1
Percentage . .	4	8	12	20	14	14	12	4	10	2

Eight hundred rachillæ per earhead is the most common type met with in the Deccan variety, though the number may go to five hundred and fourteen hundred in extreme cases. (Plate VI, Fig. 2-B.)

The average number of rachillæ in different parts of the earhead. In the case of the fifty earheads already referred to, the distribution of the rachillæ in five equal divisions of the head was studied and the average number found in each part is shown in the following Table :—

Average No. of rachillæ in different fifths of earheads	Parts of earhead				
	Base.....to.....apex.				
	135	202	226	211	152
Average total No. of rachillæ 924 (=average of 50 heads).					
Percentage.	14·4	21·9	24·4	22·8	16·5

The number was maximum in the middle one-fifth, but it decreased gradually in both directions. (Plate VII, Fig. 1-A.)

The density of rachillæ. The number of rachillæ on the unit surface of the rachis at its middle was studied in the case of the fifty earheads already mentioned. The middle portion, which is less liable to vary in thickness, was thought to be more suitable for comparison. The results obtained are given in the following Table :—

No. of rachillæ per Sq. cm.	50	60	70	80	90	100	110	120	130	140	150	160	170	180
No. of earheads (Total 50).	2	2	4	8	10	8	4	3	3	2	3	0	0	1
Percentage . .	4	4	8	16	20	16	8	6	6	4	6	0	0	2

The figures show that there is a great variation in the density of the rachillæ in the middle portion of the earhead. Fifty and one hundred and eighty rachillæ per square centimetre were the extreme cases found. Ninety rachillæ per square centimetre was the most frequent number in earheads of the Deccan variety. (Plate VII, Fig. 1-B.).

The Spikelets. It has been already stated that at the end of each rachilla there is a whorl of bristles enclosing several spikelets—usually two. The whorl consists of 35 to 40 bristles when it encloses only one spikelet, but the number of bristles goes on decreasing along with the increase in the number of spikelets within the whorl. The bristles are almost as long as the spikelets, slightly curved in shape and possess a scabrid surface. The outer ones are not hairy and are somewhat shorter than the inner ones, but the latter, though hairy, sometimes drop their hairs especially from the upper portions of the bristles. In thickness the inner ones slightly exceed the outer. In awned varieties some of the inner bristles elongate three to five times their usual length and form what are known as awns. The bristles or the awns in some cases have a pinkish colour varying widely in intensity.

Enclosed within the whorl of bristles there is a group of spikelets usually two, but the number may vary from spike to spike and also in different parts of the same spike. There are usually two flowers in the spikelet, the lower one being male and the upper hermaphrodite. The length of the spikelet varies from 3 to 6 millimetres in different types.

The total number of spikelets in the earhead varies considerably in different types according to the number of rachillæ and also the number of spikelets on each rachilla. In order to have some idea as to the variation of this number, the fifty earheads already referred to were examined and the results obtained are shown in the following Table :—

No. of spikelets	875	1,125	1,375	1,625	1,875	2,125	2,375	2,625	2,875	3,125
No. of earheads	2	3	8	13	9	7	5	1	1	1
Percentage	4	6	16	26	18	14	10	2	2	2

The most frequent number of spikelets per earhead is 1,625, with 875 and 3,125 as extreme cases. (Plate VII, Fig. 2-A.)

The average number of spikelets in different parts of the earheads. The distribution of the spikelets in different parts of the earheads was also studied side by side in the above fifty earheads. The earhead was divided into five equal lengths and the

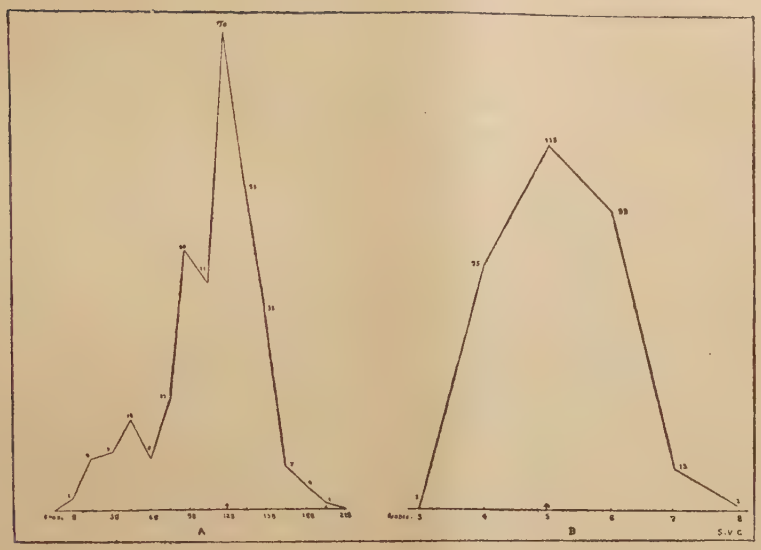


FIG. 1.

A. Frequency curve showing the height of plants.

B. Frequency curve showing the node at which the earhead is borne.

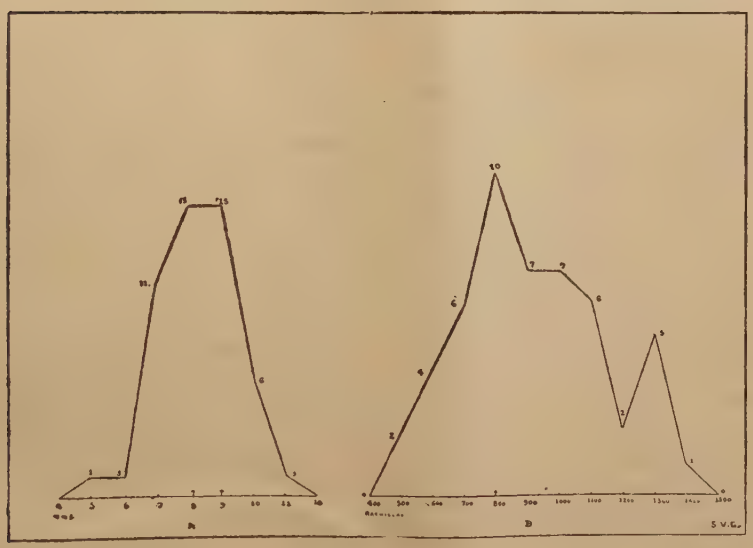


FIG. 2.

A. Frequency curve showing the circumference of the rachis at the middle.

B. Frequency curve representing the number of rachillæ in different earheads.

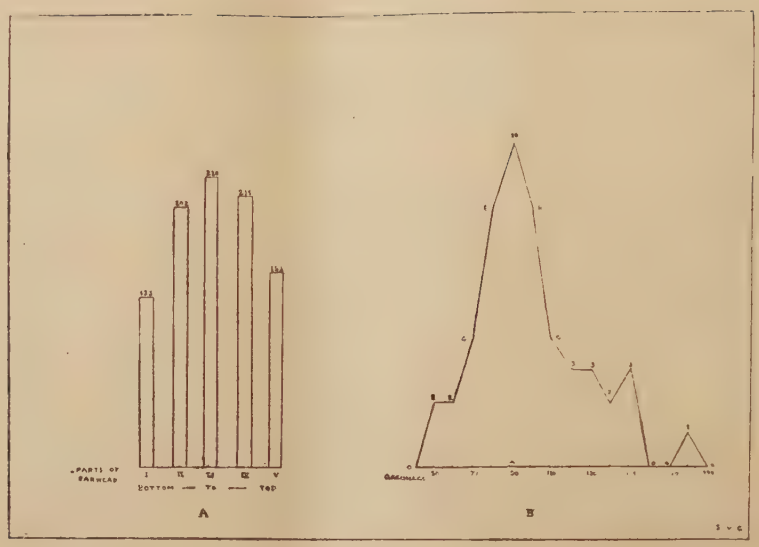


FIG. 1.

A. Average number of rachillæ in different parts of earhead.

B. Frequency curve showing the number of rachillæ per square centimeter.

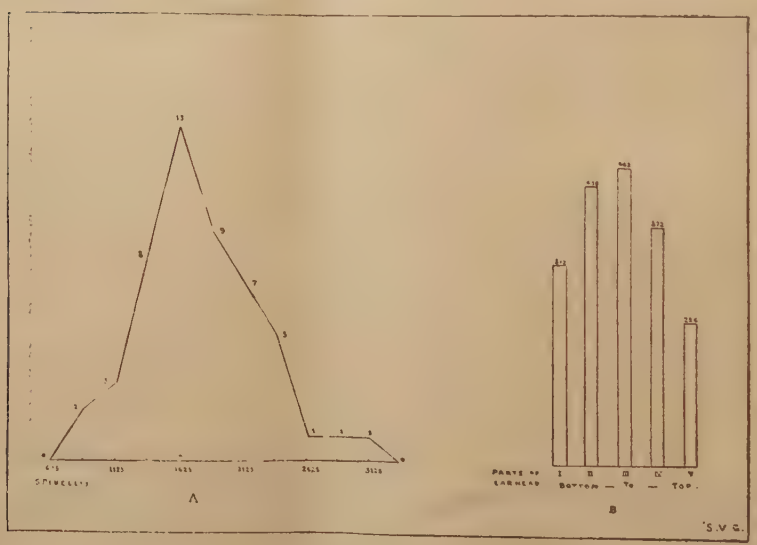


FIG. 2.

A. Frequency curve showing the number of spikelets in earheads.

B. Average number of spikelets in different parts of earhead.

number of spikelets noted in each division. The average number found in each part is shown in the following Table :—

Parts of earheads	BASE.....TO.....APEX				
	1/5	1/5	1/5	1/5	1/5
Number of spikelets in each. Total 1810.	312	438	462	372	226
Percentage	17·3	24·2	25·5	20·5	12·5

More than twenty five per cent. of the total number of spikelets were found in the middle fifth of the earhead and the number gradually decreased towards both ends of the earhead. The extent of the decrease in the upper part was much more than that in the lower part of the earhead. (Plate, VII, Fig 2-B).

Different number of spikelets found on the rachillæ. In order to study the variation in the number of spikelets found on the rachillæ, the rachillæ of the above fifty earheads were examined and the number of spikelets in each case was noted. The groups of rachillæ bearing different number of spikelets are shown in the following Table and also represented in Plate IX, Fig. 1-A.).

No. of spikelets	1	2	3	4	5	6	7	8	9	10
No. of rachillæ. Total 46,247.	7,646	33,651	4,498	364	61	20	6	0	0	1
Percentage . .	16·5	72·8	9·7	·8	·15	·05	0	0	0	0

The number of spikelets varied widely from 1 to 10 per rachilla. More than seventy-two per cent of the rachillæ bore two spikelets each. Amongst the rest those with one and three were present to an extent of twenty-six per cent. All the rest did not form even one per cent. of the total number. (Plate IX, Fig. 1-A.).

Variation in the number of spikelets per rachilla in different parts of the earhead. The average number of rachillæ found in each of five equal parts of the earhead. has already been given, while the number of spikelets borne by those rachillæ has been also mentioned. From these two figures, the number of spikelets per 100 rachillæ in different parts of the earhead has been obtained and shown in the following Table, as also in Plate IX, Fig. 1-B)

Parts of earhead	BASE.....TO.....APEX.				
	1/5	1/5	1/5	1/5	1/5
Number of spikelets per 100 rachillæ .	235	216	204	176	148

The average number of spikelets per rachilla in five equal parts of earhead decreases from below upwards. In the lowermost one-fifth, it is 2 35, in the middle slightly above 2, and in the top one-fifth it is approximately 1·5 per rachilla. (Plate IX, Fig. 1-B.).

The bajri flower. The spikelet which is shortly pedicelled is usually ovate or oblong in form. It consists of two flowers lying closely together, of which the hermaphrodite one is slightly longer than the other which is staminate. (Plate VIII.)

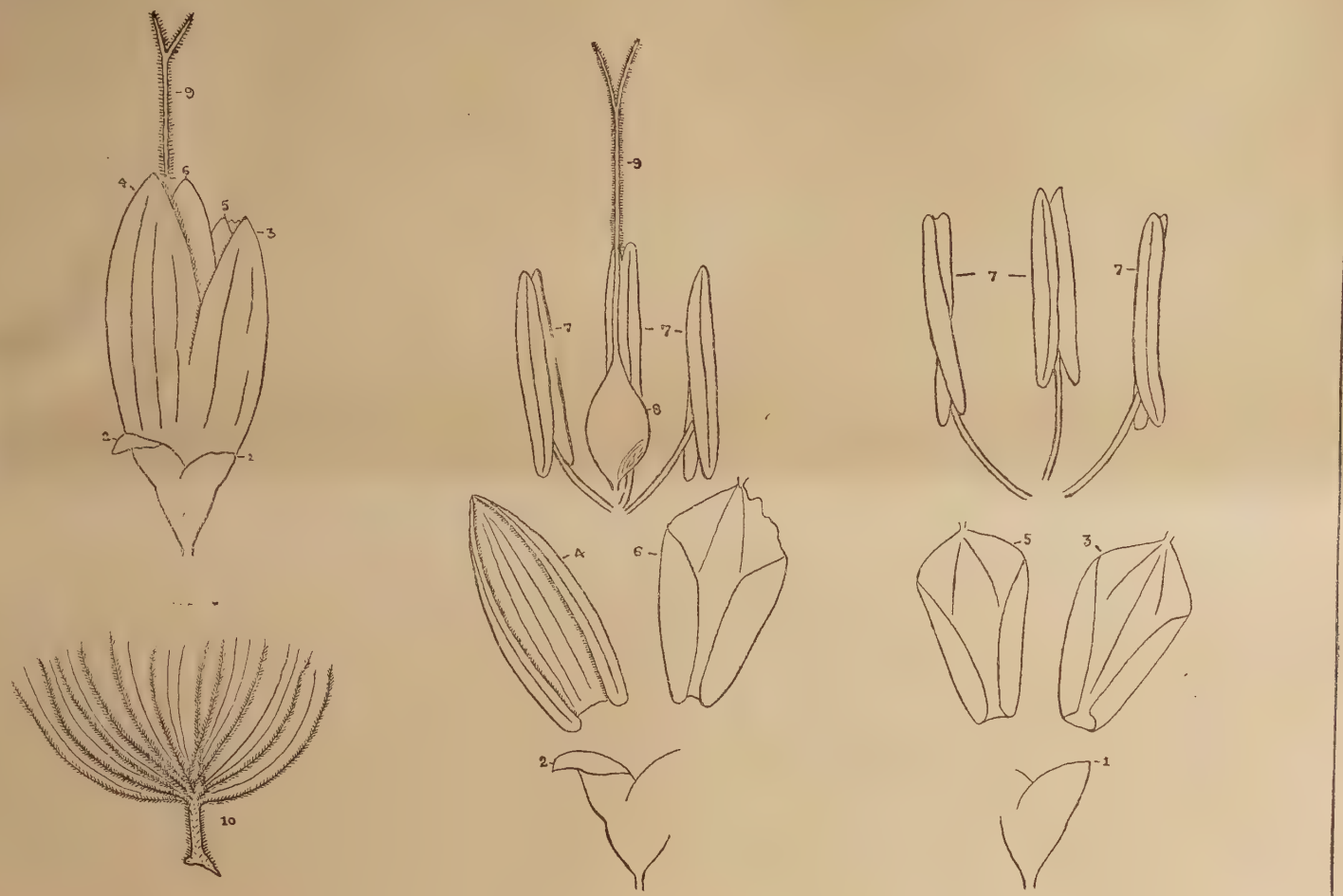
The empty glumes (I & II) are quite rudimentary often reduced to small membranous bands. The two inner glumes (III & IV) differ slightly from one another in form. Glume III which contains the staminate flower, is somewhat smaller than glume IV and slightly broader at the apex and possesses only 3 nerves, while glume IV which contains the hermaphrodite flower is ovate, 3·5 mm. long, glabrous, 5-7 nerved, with incurved ciliate margins and acute apex. The paleae in both cases are two nerved, broad, delicate, thick and translucent structures encircling the stamens. Lodicules are however absent. The stamens are three with filiform filaments and versatile linear anthers. The ovary is monocarpellate, one-celled, containing a single ovule. The style which divides itself into two branches in its upper part possesses stigmatic hairs over its surface, each of which is capable of admitting pollen tubes.

Variation in the nature of flowers. A slight variation from the usual nature of the flowers in spikelets has been found in a very few instances. In all cases of involucels containing one spikelet, the flowers of the normal type, *i.e.*, one hermaphrodite and one staminate, were found. In cases having two spikelets each, the staminate flower was absent in one or both spikelets. When the involucels contained three spikelets, one of them possessed both flowers staminate. Lastly, only in one case of an involucel containing four spikelets, the staminate flower was absent in one of them. In no case, the spikelet consisted of more than two flowers.

Pollination. The main inflorescence of *bajri* emerges within five to ten weeks from the date of sowing, but this period may vary according to variety, climate and other unknown factors. The appearance of the spike is accompanied by the rapid elongation of the peduncle and also the internodes below it.

Two to three days after its emergence, styles begin to protrude first at the top, then gradually downwards, requiring usually twenty-four hours to reach the base of the spike. The styles, to attain their full length of 5 to 7 mm., require thirty-six to forty-eight hours and after remaining fresh for a day or two later, they begin to dry up.

Just after the styles have started drying up or a little later, the anthers push themselves out of their glumes, first in the region slightly above the middle of the spike and continue to appear both upwards and downwards, taking usually forty-eight hours to reach the basal portion. Late in the season, the styles, as also the anthers, take a longer time to finish their protrusion and sometimes the anthers start appearing from the top instead of slightly below it.



The structure of the *Bajri* flower.

1. Glume I. 2. Glume II. 3. Glume III. 4. Glume IV. 5. Palea I. 6. Palea II. 7. Anther. 8. Ovary. 9. Style. 10. A whorl of bristles.

PLATE VIII.

In any spikelet, the anthers of the hermaphrodite flower appear two to three days earlier than those of the staminate. The same thing happens when there are two or more spikelets in an involucel. This is how a new series of anthers is often seen protruding from regions already covered with anthers.

The opening of the anthers takes place from the tip downwards. They have been found to dehisce at any hour during day time, but evidence is lacking as to what extent this happens during the night. Early in the morning, however, a great many anthers are usually seen undehisced, which suggests that the dehiscence has either stopped or proceeded at a slower rate.

The protogynous nature of the flowers as described above suggests the vast extent of cross-pollination that is taking place in this crop. Even if there be a larger number of styles looking quite fresh when the anthers first appear, the abundance of foreign pollen already floating in the air scarcely provides an opportunity for self-pollination to take place. In the lowermost part of the spike, however, the styles, owing to their late emergence stand some chance of coming across pollen derived from the same inflorescence.

If the access of foreign pollen be prevented by putting over the spike a close-meshed cloth bag immediately after its emergence, the styles that appear within do not dry up as early as they do when exposed. This is probably due to the greater humidity within the bag and also the delayed (here. self) pollination which does not induce them to dry up earlier. The bagged earheads set well and produce grains all over to the fullest extent.

Individual cross-pollination is too difficult to practise to any extent. It has been observed that the styles and also the anthers in the lowermost part of the spike are the last to appear ; but the time taken by the anthers to spread to the lowermost part of the spike is much more than is required by the styles. Thus the interval between the appearance of the styles and the anthers is greater in the lowermost region than in any other. This difference in period may be taken advantage of in cross pollinating *bajri* flowers. The first step would be to cut off the upper four-fifths of the spike and bag the rest before any styles appear. After two or three days when the styles appear fully, pollen from a previously bagged inflorescence should be brought and dusted over the styles, taking care not to expose the latter except during the period necessary for the operation. The above should be repeated three to four times at convenient intervals before any anthers appear. If, however, the pollination is delayed, the styles may not dry early with the result that the anthers in that region may appear and vitiate the purpose.

In seven to eight days from the first appearance of the spike, the emergence of anthers comes to a close and the development of the ovary commences. By the end of the first week of its growth, the ovary grows so much as to become visible outside the glumes and its contents, which were watery in the beginning. begin to turn milky. A week later, it is found to have developed into a full-sized grain. During the following week, the grain hardens gradually while the colour also changes from white to dull bluish green.

The Bajri Earhead.

The earhead is the most important part of the plant that has to be studied in detail. The advantages or otherwise of any variation in the plant will have, in most cases, to be judged by the size of the head and by the grain yield.

From the time of the first appearance of the spike to the complete ripening of the grains, the period is usually four weeks or slightly less. In late varieties this period is slightly more, but there are no further data to show as to whether this period is proportional or not to the total life period of such late plants.

In shape, the earhead varies considerably in different varieties. The most common form of earhead is a cylinder with a slightly tapering cone in the uppermost one-third. Perfectly cylindrical heads are also found especially in varieties with very short rachillæ. At times, the lower portion of the cylinder is reduced in thickness and spindle-shaped earheads are formed.

The compactness or looseness in earheads is a combined result of three different factors. The first of these is the distribution of rachillæ on the surface of the rachis. Evidently, the greater the number per unit surface, the more will be the compactness. The length of rachilla is another factor that affects compactness. When rachillæ are short, the earhead appears compact, and as their length increases, the space surrounding each group of spikelets will naturally increase, thereby causing sparseness or looseness in earheads. The third factor is, however, the space that is occupied by each group of spikelets which increases with the size and number contained in each involucel.

The length. The length of earhead is subject to extreme variation depending on the variety, season, soil, moisture, manure, etc. In certain varieties, for instance Gajvel, long earheads with very short rachillæ are formed while in some others thick and short earheads are usually produced. The Deccan variety, however, produces a medium-sized earhead, neither long nor broad. In order to study the variation in the length of earheads in the Deccan variety, one hundred and fifty earheads were selected at random in a normally grown crop and their length measured. The results are shown in the following table :—

Length of earhead in cm.	9	10	11	12	13	14	15	16	17	18	19	20
No. of heads. Total 150 .	3	7	19	22	30	29	14	14	5	2	3	2
Percentage . . .	2	4·7	12·7	14·7	20	19·3	9·3	9·3	3·3	1·3	2	1·3

Thirteen centimetres is the most frequent length in earheads that have been examined. Nine and twenty centimetres were the extreme cases. The above should not be taken to mean that there can be scarcely any earheads beyond the limits mentioned above. (Plate IX, Fig. 2-A.).

The circumference. The circumference which varies according to the diameter or the thickness of the head is dependent on three factors. The first of these is the

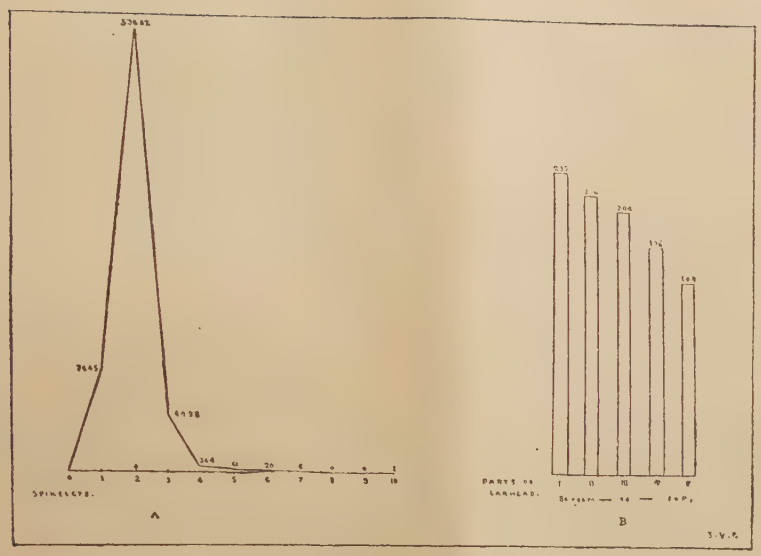


FIG. 1.

A. Frequency curve of the number of spikelets on one rachilla.

B. Average number of spikelets per hundred rachillæ in different parts of earhead.

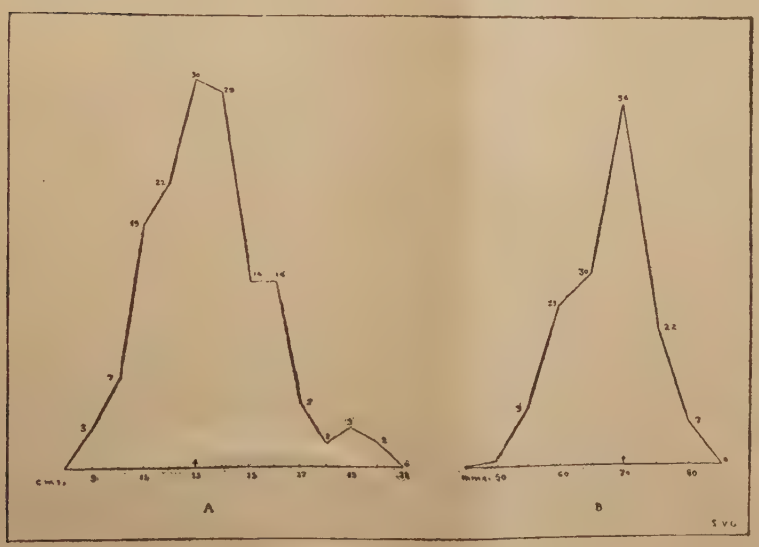


FIG. 2.

A. Frequency curve showing the length of earheads.

B. Frequency curve showing the circumference of the spike.

LATE X.

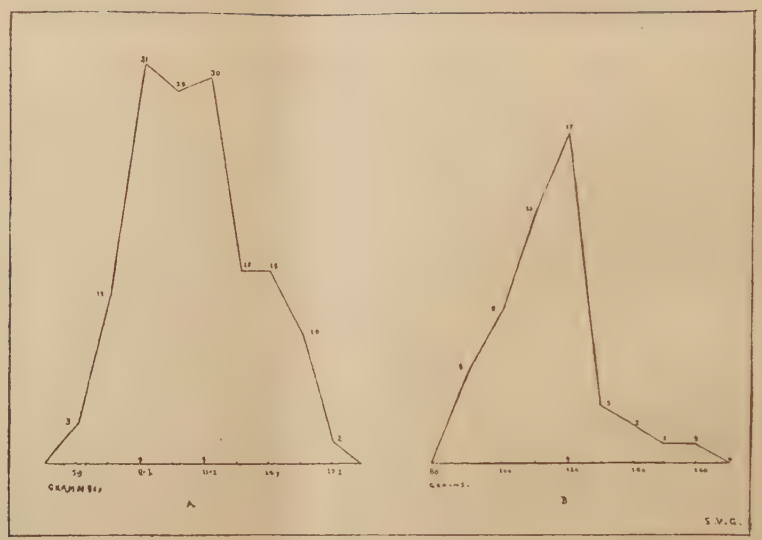


FIG. 1.

A. Frequency curve showing the grain yield of earheads in grammes.

B. Frequency curve showing the number of grains per gramme in different earheads.

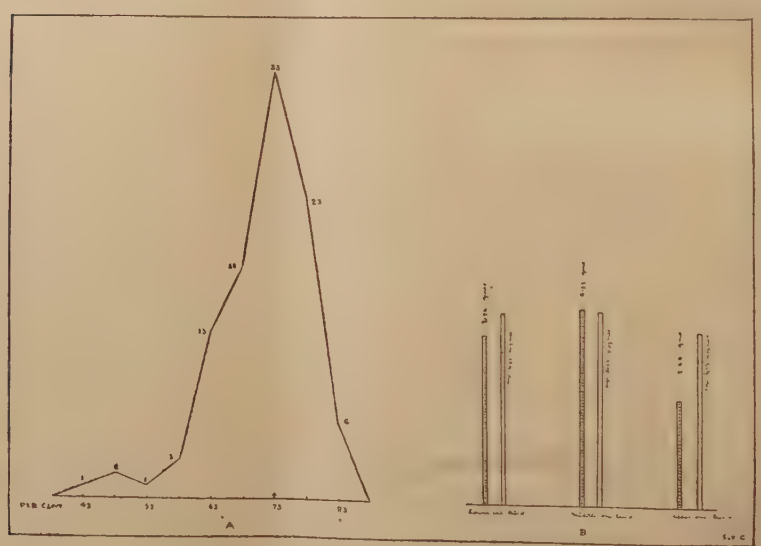


FIG. 2.

A. Frequency curve of the grain percentage in different earheads.

B. Comparison of the size and quantity of grain in different parts of earheads.

thickness of rachis; the second, the length of rachillæ and the third, the length of the spikelets. It has been mentioned in a previous chapter that in the case of inflorescences having thick rachis, the rachillæ are rather short. The variation in circumference has been studied in the case of the same one hundred and fifty earheads selected for the length measurements. The analysis of the figures is shown in the Table below and graphically in Plate IX, Fig. 2 B.

Circumference of the spike in cm	5·0	5·5	6·0	6·5	7·0	7·5	8·0
Number of heads. Total 150 . . .	1	9	25	30	56	22	7
Percentage	·7	6·0	16·7	20·0	37·3	14·7	4·7

Seven centimetres was found to be the most frequent circumference, while five and eight centimetres being extremes. Plate IX, Fig. 2 B.

The grain yield. The weight of grains obtainable will vary according to the fertility and the size of the earhead. At times, most of the grains that have formed are eaten by birds in spite of the watch kept to prevent such loss.

Infertility has been often stated to be a consequence of pollen having been washed away by rain during the flowering season; but it is often found that soon after the rains some of the styles drop off in a fresh state. It is not certain as to what extent the infertility may be attributed to the washing away of the pollen or to the dropping of the styles at about the time of fertilisation.

The variation in grain yield in the Deccan variety was, however, studied in the case of one hundred and fifty earheads already referred to in this chapter. The figures are classified under groups differing by 1·5 grams and the number of individuals falling under each group is shown in the Table below :—

Weight of grains in grams .	5·3	6·8	8·3	9·8	11·3	12·8	14·3	15·8	17·3
No. of heads. Total 150 .	3	13	31	29	30	15	15	10	2
Percentage	2·0	8·7	20·7	19·3	20·0	10·0	10·0	6·7	1·3

Though the maximum number of individuals fall under the class of 8·3 grams, the two neighbouring classes, *viz.*, 9 8 and 11 3 consist of almost as large a number of individuals. Hence in this case 8·3 to 11·3 may be taken as the mode. The extreme cases of yield observed were 5·3 and 17·3 grams. (Plate X, Fig. 1 A.)

The grain size. The size of individual grains affects to a large extent the total yield of earheads. There is a great deal of variation found in the size of grains, depending both on external and internal factors. This variation was studied in the case of fifty earheads grown under normal conditions during the year 1921. None of these represented any extremely small-grained heads and hence the study

can be expected to give only a limited idea of the variation found in the normal crop. The size of grains has been indicated by the number that go to make one gram. The results are shown in the Table below :—

No. of grains per 1 gram	90	100	110	120	130	140	150	160
No. of earheads. Total 150	5	8	13	17	3	2	1	1
Percentage	10	16	26	34	6	4	2	2

One hundred and twenty grains usually go to make up one gram. (Plate X, Fig. 1 B.)

The ratio of size of head to grain yield. It is quite essential to have some idea as to the amount of grain that one should expect out of a particular sized earhead. In order to ascertain this ratio, one hundred earheads of various sizes from the Deccan variety were selected and weighed. The weight of grains obtained from each of these was expressed in terms of percentage of the weight of the earhead. The results are shown in the Table below :—

Grain percentage	43	48	53	58	63	68	73	78	83
No. of heads. Total 100	1	2	1	3	13	18	33	23	6
Percentage	1	2	1	3	13	18	33	23	6

Seventy-three per cent. is the most frequent proportion of grains found in earheads. The maximum has reached eighty-three per cent. of the weight of the earhead. (Plate X, Fig. 2 A.)

Variation in grain size in different parts of earheads. This was studied in the case of fifty earheads selected from the Deccan variety. Each earhead was divided into three equal lengths, and the grains from each part were counted and weighed. The results, as shown in the following Table, indicate the average weight of grains in different parts and also their size expressed as the number going to make up one gram.

Parts of earheads	Lower one-third		Middle one-third		Upper one-third	
	Average Weight gms.	No. per gram	Average Weight gms.	No. per gram	Average Weight gms.	No. per gram
	3·84	113·4 or 8·82 mg. each.	4·55	111·9 or 8·94 mg. each.	2·44	124·5 or 8·03 mg. each.
Per cent.	35·5		42·0		22·5	

The maximum quantity and size of grains is found in the middle one-third of earheads. The quantity and the size diminishes in the lower one-third and it is the least in the upper one-third. The average size of grains in the whole of earhead was 115·5 grains per gram or 8·66 milligrams each. (Plate X, Fig. 2, B.)

Varieties of Bajri.

Mollison[1] and Gammie[2] have each described the same five varieties of this crop as being grown in the Bombay Presidency. The distinctions between these varieties are somewhat marked. There is at least one more variety not included in the above descriptions which is very late and is grown in the Bijapur and Belgaum Districts.

Besides these five or six, there are many so-called varieties grown all over the Presidency often called after the names of localities in which they are being grown. Various qualities are at times attributed to these, but they do not always turn out to be true when they are tested in a different place. Akola *bajri* is probably one of these, but it is very popular in the Deccan as an early and high yielding *bajri*.

No botanical description of any of the above varieties seems to have been given anywhere. If any attempt is to be made it is necessary to describe these while growing in their own locality. About thirty lots of seed of this crop were obtained from different parts of the Bombay Presidency and grown at Poona during the last four years (1922 to 1925) to study their behaviour. Each was grown in a single row thirty to forty feet long. The seed, wherever possible, was obtained from a single earhead during the first year and from a bagged one in subsequent years. The progeny was studied for various morphological characters including detailed observations on the earhead and grain. A short account of this study is given below :—

Sind varieties. Two varieties from Mirpurkhas in Sind, of which one was what is popularly termed " awned " (but really long bristled), were grown in Poona during 1923, 1924 and 1925. The awned one produced long and moderately thick earheads bearing large grains. The leaves of this type in most cases possessed hairs at the base, some of them having hairs on the lamina and sheath in addition, while the remainder had no hairs at all. The other variety produced a smaller earhead and smaller grains too. The leaves were mostly hairy at the base except in a few instances in which they were glabrous. Both varieties possessed long bristles, but the number of such earheads was much greater in the awned than in the other. Thus, neither of the two varieties behaved as a pure stock in respect of bristle length. The big grain awned variety, however, suggests its origin from the Jabalpuri, described below :

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[1] J. Mollison. Text book on Indian agriculture Vol III (1901).

[2] G. A. Gammie. Field and garden crops of the Bombay Presidency. Department of Agriculture, Bombay, Bulletin No. 30 of 1908.

The Jabalpuri, Bhavnagari or Giant bajri. This variety has been described by Mollison as having coarse stalks and long thick spikes of large grain. Gammie says that it possesses grayish-purple bristles equalling or exceeding the spikelets. Seed of this variety was obtained from Cutch and Bhavnagar and grown separately during the last four years. Another variety by name *Bajro* was also tried, but the name was found later to be an additional synonym for the above.

All the above varieties during the four years produced long and very thick earheads having large grains. The leaves were either glabrous or hairy at the base, but in the case of *Bajro* some plants possessing fully hairy leaves were also found. The thickness of earheads in this variety is chiefly due to the greater length of the rachillæ and hence leads to less compact earheads.

Malbandro or Madhodri. Mollison says that this variety gives finer straw than *Bajro* and remarks that it is probably an offshoot from the *Deshi* variety of Gujarat. Gammie states that it differs from the last described in "The thinner and shorter grayish-purple spikes and in the more membranous glumes."

This was grown for the last four years and has produced long and thick earheads having large grains. The leaves presented all types of hairiness and complete absence of hairs as well. The plants showed a closer resemblance to Jabalpuri than to the *Deshi* variety.

Nadiad or Deshi variety. Mollison has described this variety as being perhaps more vigorous in growth than *Malbandro*, but the spikes, he says, are thinner and shorter and are dull light brown.

Four different earheads of this variety were grown separately during 1922, but only one was retained from 1923 onwards. Besides these some seed under the name *Gajwel* was also obtained from the Nadiad and Kapadwanj Talukas of the Kaira district and grown here during the last four years. All of these produced very long and thin cylindrical heads of a compact nature. The grains were fairly large. Leaves of all the usual types in respect of hairiness were present. The rachillæ are inclined to be very short in this variety and this accounts for the thinness and greater compactness of earheads. In some cases extremely long and very thick rachides are also met with.

Awned variety. Mollison refers to this variety as being sparingly grown near Petlad (near Baroda) in Gujarat and also in the Ahmednagar District. It is doubtful as to whether this exists as an independent variety. Long bristles may be found in all types of *bajri* to a smaller or greater extent. This character though heritable has not been found to be present in all progeny derived from a single earhead. None of the awned varieties tried so far have shown any distinct characters other than those that are described under different varieties.

The Deccan bajri. Mollison rightly described this *bajri* as being not so tall as other varieties and says that it produces short and thin spikes containing smal' seed. He further adds that it is a hardy variety which resists unfavourable conditions better than other varieties. Several samples of this variety each with different

ascribed qualities were tested during the last four years, but none of them have given any perfectly definite characters. Akola *bajri* has, however, showed its tendency to be slightly earlier than any of the other varieties tried so far. A sample of seed obtained from Dhulia as that of a drought-resistent and heavy-yielding type did not show any indications to that effect. Still another one from Dhulia suspected to be dwarf and early and to produce small earheads did not inherit any of these qualities. A sample from Kopargaon said to be earlier than Akola showed, on the other hand, a tendency to be slightly late. Two more samples Sajugri and Sajugra from near Pandharpur—the former described to be early, long and large grained and the latter, to be late and small-seeded—did not tally even to the seed descriptions and when grown in 1924 did not prove to be true to any of the ascribed characters. Lastly, one more head brought in 1924 from Kusamba near Dhulia and which resembled the Nadiad variety, flowered late and produced long earheads resembling the parent.

Karnatak variety. This has not been described by either Mollison or Gammie. It is quite a distinct variety different from any of those described above. It is grown chiefly in the Bijapur and Belgaum Districts of this Presidency. The plants are tall and thick-culmed producing long wide leaves very much resembling those of *Jowar.* They have a distinct spreading habit and produce many tillers. Flowering commences usually two to three weeks later than in the Deccan variety. Very long and thick earheads are often produced but the grains are not very large. Awned heads are also found mixed up in this crop. No other variety tested so far has remained so faithful to its characters as this one.

Coimbatore varieties. Two varieties were obtained from Coimbatore which are being grown since 1922. The first of these is a rainfed crop known as *Aravathan Cumbu* (*i.e.*, 60 days *Bajri*) which is sown in its native tract in September or October and harvested three months and half later, *i.e.*, in December or January. This, in comparison with the Deccan *bajri*, is found to be late by a fortnight. The other one is *Thirupathi Cumbu*, a short duration variety, sown in garden lands usually in the month of April and watered three or four times during its growth. This is found to be slightly earlier than *Aravathan Cumbu* but not in any way superior to the Deccan variety from the point of earliness.

Both of these possess long, narrow leaves, tender in appearance. The culms are somewhat thin and do not attain any great height. The earheads are long and cylindrical but much reduced in thickness. The grains are usually elongated being much smaller than those of the Deccan *bajri* and remain almost completely enclosed within the glumes. None of these appear to be hardy enough to suit the Deccan conditions.

African varieties. Two varieties, one named Bulrush and the other African, were obtained from the Agricultural College Farm, Poona, and grown during the last four years. The first of these contained a large proportion of awned heads in its progeny and the leaves being directed upwards were quite different from those

of the Deccan *bajri*. A third variety called Nigerian was brought from Mirpurkhas in 1923 and tried here for three seasons. This also produced a large proportion of awned heads. The leaves of this variety possessed no hairs either at the base of the lamina or on the sheath and lamina in general. The earheads in all the three varieties were medium sized, but the grains in the Nigerian were slightly smaller than in the other two.

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